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Paleozoic Tectono-Metallogeny in the Tianshan-Altay Region, Central Asia

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Abstract: The research on Paleozoic tectonics and endogenic metallogeny in the Tianshan-Altay region of Central Asia is an important and significant project. The Altay region, as a collision zone of the Early Paleozoic (500–397 Ma), and the Tianshan region, as a collision zone of the early period in the Late Paleozoic (Late Devonian-Early Carboniferous, 385–323 Ma), are all the result of nearly N-S trending shortening and collision (according to recent magnetic orientation). In the Late Devonian-Early Carboniferous period (385–323 Ma), regional NW trending faults displayed features of dextral strike-slip motion in the Altay and Junggar regions. In the Tianshan region, nearly EW-trending regional faults are motions of the thrusts. However, in the Late Carboniferous-Early Permian period (323–260 Ma), influenced by the long-distance effect induced from the Ural collision zone, those areas suffered weaker eastward compression, the existing NW trending faults converted into sinistral strike-slip in the Altay and Junggar regions, and the existing nearly E-W trending faults transferred into dextral strike-slip faults in the Tianshan region. The Rocks of those regions in the Late Carboniferous-Early Permian period (323–260 Ma) were moderately ruptured to a certain tension-shear, and thus formed a number of world famous giant endogenic metal ore deposits in the Tianshan-Altay region. As to the Central Asian continent, the most powerful collision period may not coincide with the most favorable endogenic metallogenic period. It should be treated to "the orogenic metallogeny hypothesis" with caution in that region.

Key words: tectonics, endogenic metallogeny, long distance effect, Tianshan-Altay region

In recent years, in the research of Asian tectonics and in the compilation of the Asian Tectonic Unit Map (Wan, 2013), the authors are deeply attracted by tectono-metallogeny in the Tianshan-Altay region, Central Asia. Now the authors propose some new ideas and are interested in discussion with the readers.

1 Tectonic Background

The Tianshan-Altay region is located in the boundary region of Kazakhstan, Kyrgyzstan, Uzbekistan, Mongolia and northwest China in Central Asia. This region is a famous endogenic metallogenic belt in the world. In the sense of tectonic unit, the Tianshan-Altay region belongs to the Central Asia-Mongolia tectonic domain. The Central Asia-Mongolia tectonic domain is composed of many tectonic units, such as the Early Paleozoic (500–397 Ma) Altay-Central Mongolia-Hailar accretion collision zone, Early Paleozoic (500–397 Ma) Karaganda-Kyrgyz accretion collision zone, Turan-Karakum Plate, Late Paleozoic (385–323 Ma) Western Tianshan accretion collision zone, the Late Paleozoic (385–323 Ma) Balkhash-Tianshan-Hingganling accretion collision zone and Junggar block (Wan, 2013). The so called "accretion collision zone" refers to those with large and complicated continent-continent collision zones, which include remained sheets of the ancient continent, island arcs, oceanic crust and mantle, etc. However, some scholars still more like to use the old term "orogenic belt", which is conventionally based on the hypothesis of platform and geosyncline. It will become unacceptable when the plate tectonics theory has been recognized. The Altay region (north of the Tianshan-Altay area) is mainly the Early Paleozoic collision zone (Yakubchuk, 2004). The Tianshan region (south of the Tianshan-Altay area) is mainly the Late Paleozoic (385–323 Ma) collision zone and includes a lot of older and smaller metamorphic crystallized blocks (Pirajno et al., 2011). Following the Siberian Plate, they migrated from the southern hemisphere to the mid-high latitude of the northern hemisphere (Wan and Zhu, 2011). After the above two Paleozoic collisions amalgamated to the southwestern Siberian plate, they also can be treated as accretion of the Siberian plate in the Paleozoic (Wan, 2011).

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Taking the modern magnetic direction as a standard, the Tianshan-Altay region is the result of two nearly N-S direction collisions, occurring in the Early and Late Paleozoic, whose geological structure was almost ultimately stabilized under the influence of Paleozoic tectono-magmatism events. The previous hypothesis about existence of the "Kazakhstan Plate" in Central Asia now seems inappropriate (Li et al., 2008; Petrov et al., 2008; Pubellier, 2008). The violent Paleozoic collisions and multi-period tectono-magmatism events were developed in this region. The latest results have modified the former hypothesis and suggest that its major components are formed by collisions in the Paleozoic (Li et al., 2008; Petrov et al., 2008; Pubellier, 2008). The so called "Kazakhstan Plate" in fact is many continental blocks, included many old, small crystallized continental blocks (formed before 500 Ma) in the Paleo-Tethys Ocean, which amalgamated each other during the Paleozoic collisions. Only the Turan-Karakum Plate has a relatively stable crystallized basement.

2 Two Tectono-Thermal Events in the Late Paleozoic

No dispute arises on the Early Paleozoic Karaganda-Kyrgyz and Altay-central Mongolia-Hailar collisions in recent years (Allen et al., 1992; Xiao et al., 1992; Che et al., 1994; Yakubchuk, 2004; Charvet et al., 2007; Xiao et al., 2010; Wan, 2011), that is to say, collisions in the Altay region mainly occurred in the late period of the Early Paleozoic (~400 Ma). However, the controversy comes up on the accretion collision zone in the western Tianshan, Balkhash-Tianshan-Hingganling in the late Paleozoic, as well as on whether there were tectonic events in the Late Paleozoic in the Altay region.

It has been convinced that two tectonic events occurred in the Tianshan region for a long time. Xie (1936) firstly divided the Tianshan tectonic events into two periods, and recognized that the first one was in the Late Devonian, or at the end of the Early Carboniferous, and the second one was at the end of the Late Carboniferous-Early Permian period. Two obvious angular unconformities existed in that region. For several decades, this cognition has been cited by many researchers and two collision events or orogenesis had always been thought to occur in the Tianshan region (Xiao et al., 2010; Wan, 2011). The first collision in the Late Devonian-Early Carboniferous period has been agreed by many researchers for a long time (Allen et al., 1992; Xiao et al., 1992; Che et al., 1994; Charvet et al., 2007). The collision and related stronger tectonic deformation in the Balkhash-Tianshan area even could exert influence to the Altay region. The width of the tectonic deformation zone formed by the Late Paleozoic collision could be extended to approximately 1500 km.

In recent years, based on motion property study and isotopic dating result of NW trending faults near the Altay region, which achieved by Buslov et al. (2004), the Late Devonian-Early Carboniferous period (385–323 Ma) tectonic event was recognized as the obvious motion in this region after the Early Paleozoic collision. It forced regional NW trending faults such as Charysh-Terckta and Talas-Ferganan to display dextral strike-slip features. Those approximately E-W trending faults, which formed in the main collision zone in the Tianshan region, are generally acknowledged to have displayed the thrust features in the Late Devonian-Early Carboniferous period (Fig. 1; Li et al., 2002; Wang et al., 2008; Xiao et al., 2010; Wan, 2011). Integrating the above-mentioned data and referring to the modern magnetic direction data, two kinds of faulting motions mentioned above may be caused by relatively northward migration and shortening of the Altay-Tianshan region, in which it formed the Balkhash-Tianshan-Hingganling accretion collision zone with N-S trending with recent magnetic orientation. This explanation seems to be reasonable and agreeable for many researchers (Allen et al., 1992; Xiao et al., 1992; Che et al., 1994; Charvet et al., 2007; Xiao et al., 2010; Han et al., 2011; Wan, 2011; Fig. 1, the main collision trending noted by large red arrows).

The second tectonic period at the end of the Late Carboniferous to Permian period (323–260 Ma) is also recognized by many researchers (Zonenshain et al., 1990; Shi et al., 1994; Bazhenov, 2003; Gao et al., 2006; Pickering et al., 2008; Xiao et al., 2008; Xiao et al., 2010; Han et al., 2011) in the Balkhash-Tianshan region. It should be concerned about the fact that tectonic events in the Late Carboniferous-Permian period forced a series of the existing NW-direction faults (such as faults in the Chara, Irtysh, Krail Kuznetsk-Teletsk-Bashkauss and Balkhash as well as in Altay and its eastern areas) to show characteristics of a large-scale sinistral strike-slip (the upper part of Fig. 2; Buslov et al., 2004; Xiao et al., 2008). Its moving and slipping characteristics are completely different from those of the Late Devonian-Early Carboniferous period. Han et al. (2011) also confirmed that NW trending faults (ophiolites existed in the past), which are located between the western Junggar and Yili blocks in Tianshan, changed to be sinistral strike-slip faults after the Early Carboniferous. The isotopic dating age of the associated granitic intrusion is 320–270 Ma and this intrusion is thought to be a product of post-collision. They cited the results of Bakirov and Kakitaev (2000), as well as Biske and Seltmann (2010), and pointed out that the central Tianshan-Kyrgyz-Yili block might have been

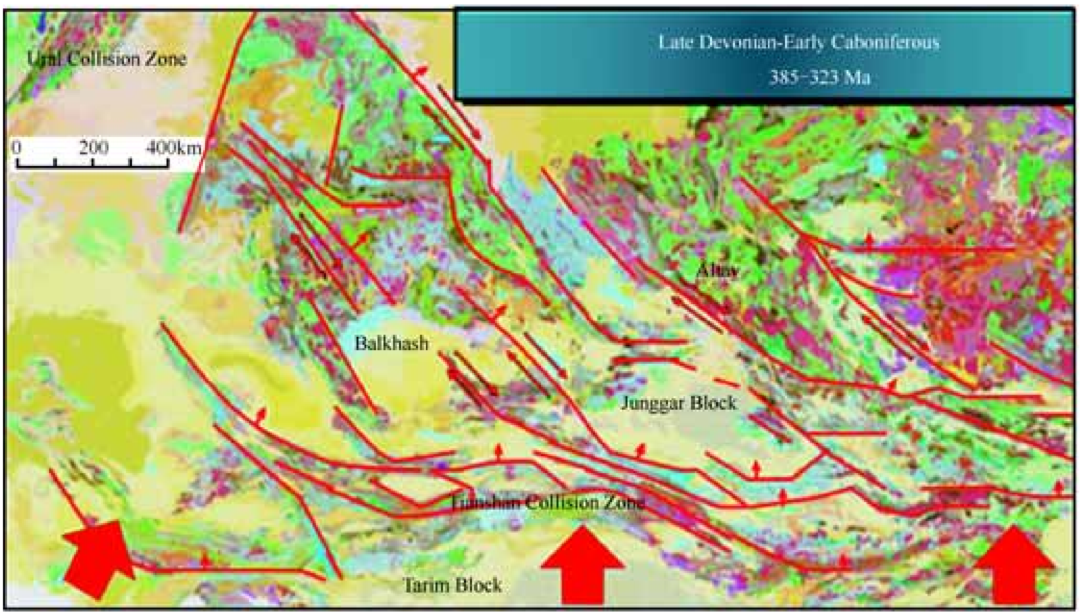

Fig. 1. The regional maximum principal compressive stress and fault motions in the Altay-Balkhash-Tianshan region during the main collision period (Late Devonian-Early Carboniferous) (According to data from Xiao et al., 1992; Allen et al., 1992; Che et al., 1994; Buslov et al., 2004; Charvet et al., 2007; Xiao et al., 2010; Han, 2011; Wan, 2011).

The big red arrow shows the trending of regional compression and collision. Small red arrows represent reverse faults with nearly EW-trending and a pair of red arrow shows the NW trending dextral strike-slip fault.

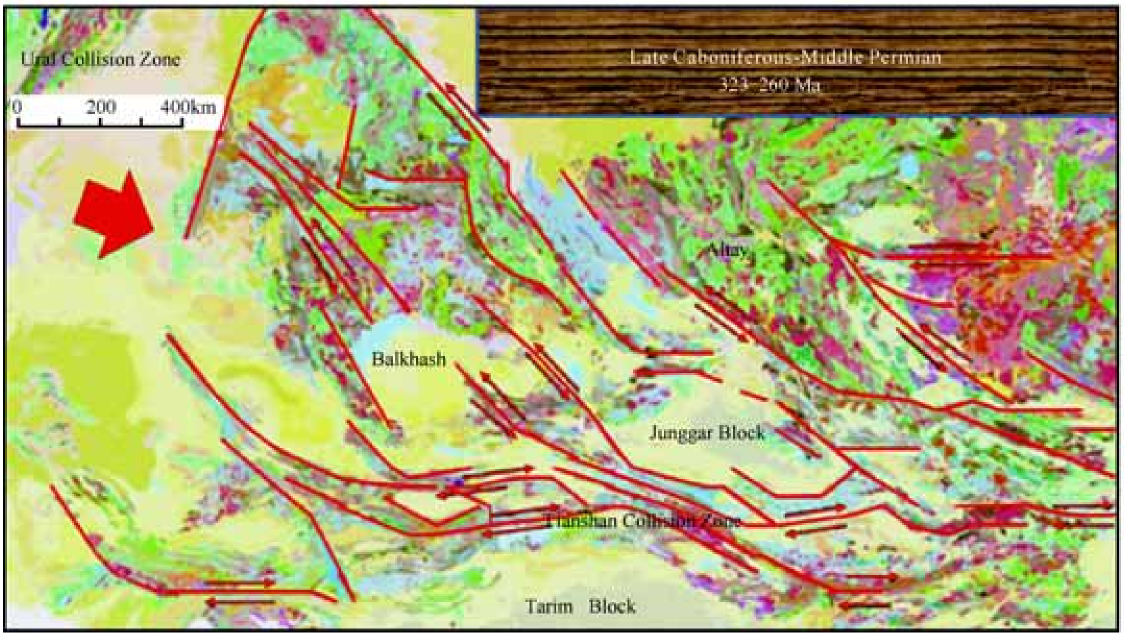

Fig. 2. The regional maximum principal compressive stress and strike-slip directions of faults in the Balkhash-Tianshan-Altay region during the post collision period (Late Carboniferous-Early Permian) (According to data of Zonenshain et al., 1990; Shi et al., 1994; Li et al., 2002; Bazhenov., 2003; Gao et al., 2006; Pickering et al., 2008; Xiao et al., 2008;Wang et al., 2008; Han, 2011).

The big red arrow shows the trending of regional compression and shortening. A couple of small and red arrows show the dextral or sinistral strike-slip fault.

pushed eastward into the space between the southern and northern Tianshan areas of China.

Li et al. (2002) and Wang et al. (2008) studied the activities and ^{40}Ar-^{39}Ar ages of nearly E-W trending regional faults in the Tianshan region. They recognized that these E-W trending faults were thrusting in the Devonian-Early Carboniferous period, and all changed to be obvious dextral strike-slip faults in the Late

Carboniferous-Permian period (about 260 Ma). They also pointed out that it may result from eastward migration of the blocks in the north Tianshan area after the collision. In this regard, the eastern Tianshan (Turpan-Hami) area shows obvious evidence in the satellite image (Fig. 3). The E-W trending faults take on large-scale dextral strike slip characteristics. Laurent-Charvet et al. (2002, 2003), Buslov et al. (2004), Natal'in and Sengor (2005) and Van der Voo et al. (2006) acquired similar results. They all considered that nearly E-W trending regional faults displayed characteristics of strike-slip faults rather than thrusts in the Late Carboniferous and Permian periods.

Integrating the recognition of Buslov et al. (2004), Wang et al. (2008), Xiao et al. (2010) and Han et al. (2011) on faulting activities in the Balkhash-Tianshan-Altay region, it can be found that NW trending faults demonstrated dextral strike-slip activities, while nearly E-W trending faults show characteristics of thrusts in the Late Devonian-Early Carboniferous period (385–323 Ma). It indicates that this region suffered shortening and collisions in the nearly south-north direction (Fig. 1). This is due to effects of collisions in the Late Devonian-Early Carboniferous period in this region. However, the tectonic event in the Late Carboniferous-Early Permian period (323–260 Ma) forced the NW trending faults change to large-scale sinistral strike-slip faults and the nearly E-W trending faults change to dextral strike-slip faults (Fig. 2; Zonenshain et al., 1990; Shi et al., 1994; Li et al., 2002; Bazhenov, 2003; Gao et al., 2006; Pickering et al., 2008; Xiao et al., 2008;Wang et al., 2008; Han et al., 2011). This dynamic mechanics could not be interpreted by collisions in the N-S direction. Obviously, the direction of the maximum principal compressive stress should be near the acute angle bisector of NW and E-W trending faults in the Late Carboniferous-Early Permian period (323–260 Ma) (Figs. 2 and 3). It is most likely to be a phenomenon

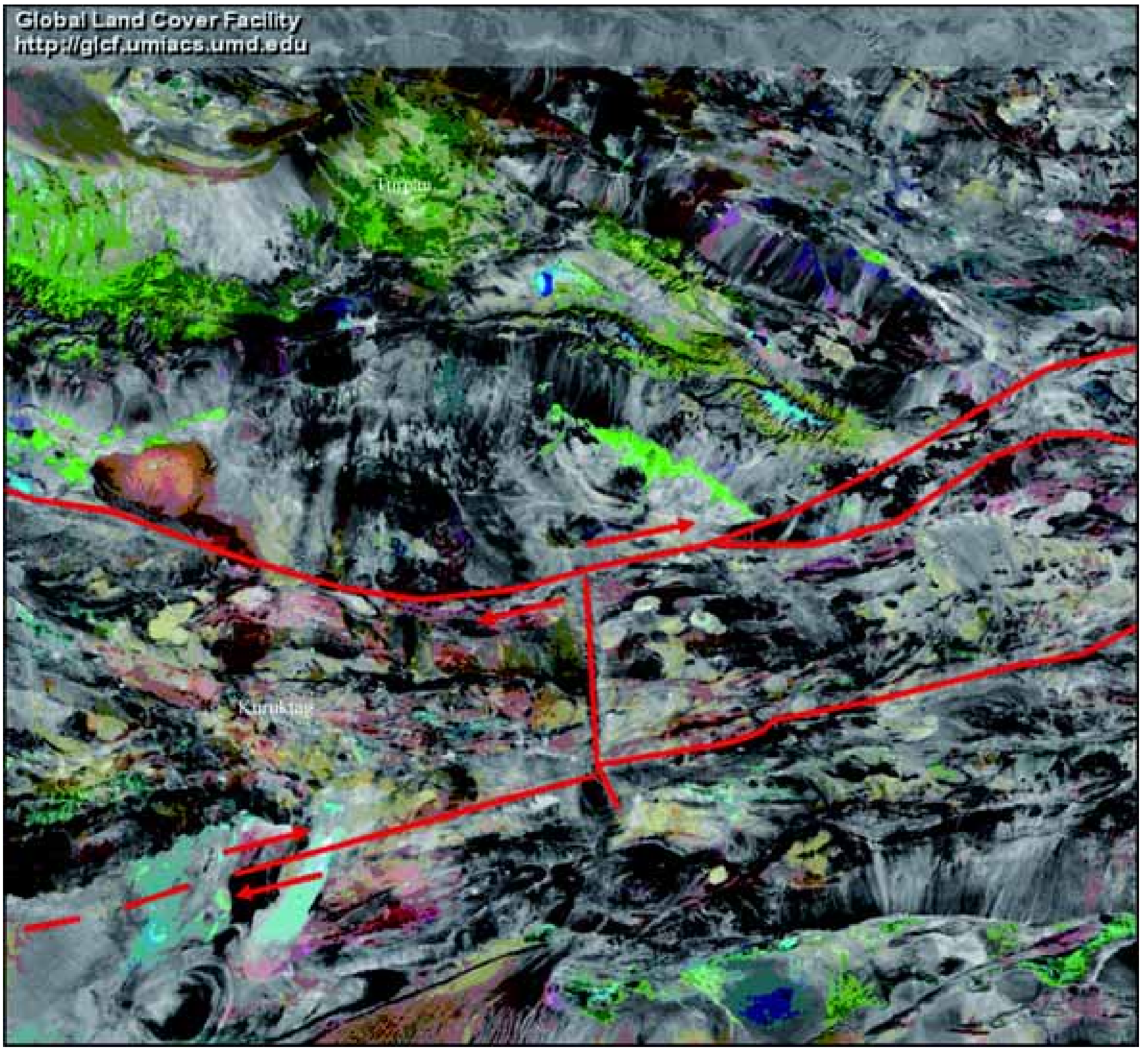

Fig. 3. The satellite image of the southern Turpan-Hami region, Xinjiang, China, showing nearly E-W trending faults displayed dextral strike-slip features during the Late Carboniferous-Permian.
This image is provided by Wang Xiaoniu (personal communication).

induced by the tectonic action from west to east. Therefore, the authors deduced that the E-W trending compression is possibly a long-distance effect of the eastward squeeze of the Ural collision zone (Fig. 2). This period can also be named the post-collision period. As a matter of fact, the distinct intra-plate deformation occurred later in the older collision zone.

In general, the strength of nearly E-W squeeze in the Late Carboniferous-Early Permian period was rather limited. It did not promote the fundamental change of the foliation in the whole region, but only formed new slipping along the existing faults, changed slipping directions on the former faults and induced some local folds, fracture zones and joint systems.

The old recognition has remained disputable on the study of Central Asia tectonics in a long time. The convergences and collisions in the nearly N-S trending formed Altay-central Mongolia-Hailar, Karaganda-Kyrgyz accretion collision zone in the early Paleozoic (500–397 Ma) and the Balkhash-Tianshan-Hingganling accretion collision zone in the late Paleozoic (385–323 Ma). Why did their western part, near Kazakhstan and Balkhash, demonstrate meniscus tectonic belts, which were completely inharmonious with the whole tectonic line direction, and that changed the trending from NW to nearly N-S, NE and E-W. Xiao et al. (2003, 2009, 2014) named them the "Kazakhstan and Balkhash Orocline". His research revealed that those two oroclines emerged in the Carboniferous and formed into a pattern mainly in the Middle Permian, maybe to the Early Triassic. Analyzed by associating the activities that the NW trending existing faults changed to sinistral strike-slip faults, and the E-W trending existing faults changed to dextral strike-slip faults with the formation of the Kazakhstan and Balkhash Orocline, it seems reasonable if interpreting those as being affected by the long-distance effect of eastward migration caused by the Late Paleozoic Ural collision zone. This long-distance tectonic effect of eastward migration was frequently ignored in the past research and it is commonly thought that two periods of orogeny all existed in and near the Balkhash-Tianshan collision belt.

Another problem, namely tectonic motions of southwest Tianshan of China, deserves discussion, too. In the last decade a number of data of isotopic ages were acquired from ophiolite suite, eclogite, glaucophane and other metamorphic rocks in the Late Carboniferous-Permian period for southwest Tianshan of China (Han et al., 2011). Gao et al. (2006), Long et al. (2006) and Zhang et al. (2009) believed that the above-mentioned characteristics were two metamorphic thermal events, which happened in 326–308 Ma as well as 263–243 Ma, and were related to the collisions. The authors considered that those two metamorphic events happened after the main collision period of the Tianshan region and were induced from eastward migration and extruding of blocks between south and north Tianshan in China. Because the ENE trending is the principal direction of the main tectonic belt in the southwest Tianshan area of China and this area was affected by long-distance effects of eastward migration of the Ural collision zone in the Late Carboniferous-Permian period, a series of ENE trending fault zones show trans-pressing features. They could not only formed metamorphic-magmatic rocks similar to those formed by some collision effects, but also possess tectonic characteristics of dextral strike-slip faults. That is an intra-plate deformation phenomenon after the main collision in the Tianshan tectonic zones, which is mainly characterized by the convergence-collision in the N-S direction in the Late Devonian-Early Carboniferous period. It seems inappreciative that collisions mainly occurred in the Late Carboniferous-Triassic period in southwest Tianshan of China (Zhang et al., 2009).

The eastward migration effect to the Balkhash-Tianshan-Altay region induced from the Devonian-Carboniferous Ural collision, which is thousands of kilometers away from the Balkhash-Tianshan-Altay region, and had been delayed in the Late Carboniferous-Permian period (323–260 Ma). With rough estimation, the eastward migrating and transmitting speed of this tectonic deformation is about 2.5–3.0 cm/yr, which seems relatively slow. The westward subduction and migration of the Pacific Plate in the Paleogene forced strong intra-plate tectonic deformation zone in Eastern Asia to move westward gradually. Based on related data, Wan (2011) calculated its migration speed and acquired a result 65 cm/yr, which is about 20 times of that formed by eastward migration of the Ural collision zone. It seems that the eastward compression effect formed by the Ural collision zone is not too intense. It might just cause moderate crack of rocks and change motion properties of faults or fractures. Due to this reason, it created perfect tectonic surroundings for the formation of many endogenic metallogenic ore deposits in the Balkhash-Tianshan-Altay region.

The long-distance effect of eastward migration caused by the Ural collision zone could not extend limitless. According to the recent available data, the most east affected area may reach to the Helanshan-Liupanshan region of North China. A lot of nearly N-S trending weak deformations in Early Permian granite of the western Helanshan-Liupanshan collision zone were discovered, as well as in the Alxa metamorphic basement. The zircon U-Pb dating for dioritic gneiss, quartz dioritic gneiss with garnet, granodioritic gneiss and foliation granites collected from eastern Alxa all yielded isotopic ages between 287±2.5 Ma and 269±2.4 Ma (Early-Middle Permian). The ages of LA-ICP-MS and zircon U-Pb collected from coarse-grained granodioritic gneiss and medium grain dioritic gneiss in metamorphic basement of western Alxa are between 289±3 Ma and 276±2 Ma (Early Permian) (Geng and Zhou, 2012). Although all these rock types and chemical components in the Early-Middle Permian period are different, they were all formed in a short interval of 289–269 Ma and belong to the product of the same tectono-magmatism thermal event. The formation age of granite in the Early Permian was nearly identical to the ^{39}Ar-^{40}Ar age of 288–277 Ma, which was dated from hornblende in the basement metamorphic rocks.

Based on the above data, the Alxa granite intrusions and metamorphic crystallized basement in the Late Paleozoic might have been affected by the eastward compression caused by the Ural collision. It is a tectono-thermal event associated with E-W-direction compression and collision of the Helanshan-Liupanshan region in the Late Paleozoic. Also it may be an important circumstantial evidence for the Late Paleozoic Helanshan-Liupanshan collision zone.

After the reformation of the northward collisions in the Late Devonian-Early Carboniferous period and eastward migration in the Late Carboniferous-Permian period, the tectonic model in the Balkhash-Tianshan-Altay region basically gone into a rather fixed pattern. The above region only suffered relatively weak compression in the N-S direction in the Triassic and Jurassic Period. In the Cretaceous-Paleocene period, the crust of that area was comparably stable and there was no obvious deformation. In the Eeocene and Oligocene, even to the Miocene, the E-W migration occurring in this region became much weaker and some nearly N-S trending broad and gentle folds were formed in weak strata. The processes, which caused the Tarim and Junggar blocks to subduct beneath the Tianshan and promoted the large-scale uplift in the Tianshan region, started since the Neogene, which was caused by a long distance effect of northward migration and collision of the Indian Plate (Wan, 2011).

3 Tectono-Metallogenesis

In the Karaganda-Altay region, there was a strong collision zone during the Early Paleozoic. However, in that area, many super large endogenetic metallic ore fields or deposits were formed in the Late Paleozoic, later than that collision. For example, Altay-Zaysan copper-gold-rare metals and polymetallic metallogenic belt, super large Nikolaev copper-zinc (VMS-volcanic massive sulfide) deposit and super large Zyryanovsk lead-zinc polymetallic deposit in Kazakhstan (Mao et al., 2012b). Although they are all located in the Early Paleozoic collision zone, the mineralization has a close relationship with the Late Paleozoic volcanic activities (Mao et al., 2012a; Wu et al., 1993).

An exquisite study was undertaken on the super large Koktokay granite pegmatite type rare earth metals (lithium, beryllium, niobium, tantalum, rubidium, cesium and hafnium) deposit in Fuyun County, Xinjiang Altay area. The deposit is located in the Early Paleozoic Altay collision zone, but the mineralization occurred mainly in the Late Paleozoic (330–250.3 Ma; i.e., Carboniferous-Permian; Fig. 4; Zou and Li, 2006). The ore-bearing fracture zone, mainly trending NW, was affected by the regional dextral shearing effect during the Devonian-Early Carboniferous period (345–325 Ma) and those fractures show tensile-shearing features, which conduce to the migration of pegmatite magma and ore fluid. However, in the Permian (280–270 Ma), influenced by regional sinistral shear, the mainly NW trending fractures take on compression-shear features, thus causing relatively close relations between those fractures, which facilitated the formation of pegmatite magma as well as condensation and storage of the ore-bearing fluid. For this reason a large number of ore-bearing pegmatite veins were stored.

In recent years, Wang et al. (2007) obtained a SHRIMP U-Pb zircon age of 220–198 Ma, namely in the Triassic, in No.3 pegmatite vein, which is in the Koktokay main ore body. It seems that the ore-bearing pegmatite veins were finalized in the Triassic.

On the southern margin of the Altay area, there exist a NW-direction precious metal and nonferrous metallogenic belt, and the Ashele copper zinc massive sulfide deposit is a representative (Fig. 5). The belt is located in the southwest of the Altay-Central Mongolia-Hailar collision accretion zone of the Early Paleozoic (500–397 Ma). Later strong tectono-magmatic activities were developed in the Late Paleozoic and formed the Ashele volcano rock belt and a large-scale Ashele copper zinc massive sulfide deposit. The Ashele volcanic rocks are rich in sodium and have a construction of marine spilite-keratophyre. The isotopic age of the Ashele volcanic rock is 386–352.3 Ma, and the hydrothermal mineralization age is mainly 262–242 Ma, which is in the Late Permian (Chen et al., 1996). According to the characteristics of the regional tectonic stress state, affected by NW-strike regional fault with dextral strike-slip motions in the Devonian-Early Carboniferous period (386–352 Ma), the nearly S-N direction secondary derivative fractures in the Ashele area were tensile-shear, which is conducive to the migration of ore-bearing fluids. However, since the Early Permian (280–270 Ma), when the existing NW trending regional faults transferred to sinistral strike-slip faults, the Ashele

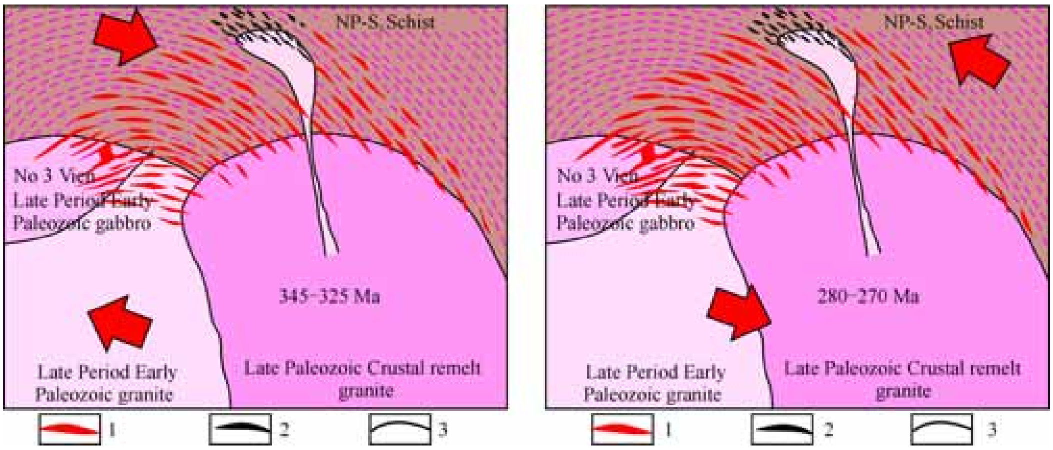

Fig. 4. Sketch of a forming model for the pegmatite type rare-rare earth metal deposit in Koktokay, Fuyun, Xinjiang (revised from Zou et al., 2006).

1, Lithium, beryllium, niobium, tantalum, rubidium, cesium and hafnium mineralized pegmatite vein group related to the late Paleozoic continental crust re-melt granite; 2, beryllium, niobium and Tantalum mineralized pegmatite vein group related to Triassic two mica granite; 3, geological boundary. The red arrows show shear direction of block.

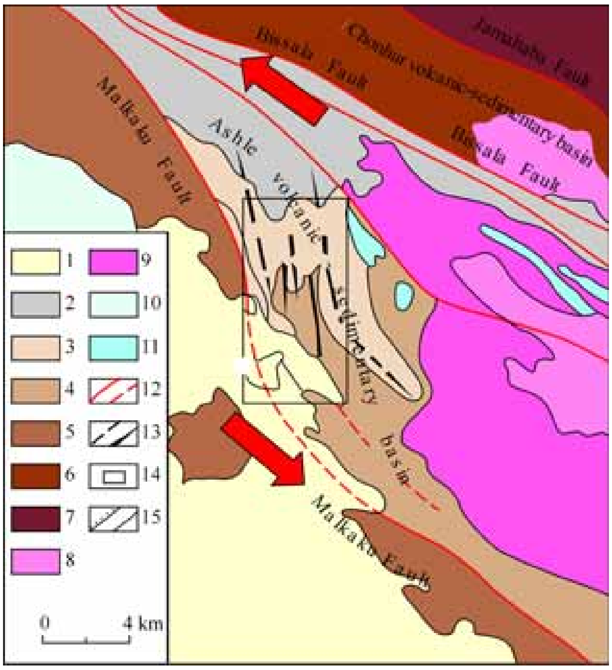

Fig. 5. Sketch map of the metallogenic belt and the volcanic rock basin in Ashele of Altay, Xinjiang, China (revised from Chen et al., 2006).

1, Quaternary; 2, Lower Carboniferous; 3, Middle-Upper Devonian; 4, Ashele Formation, Middle-Lower Devonian; 5, Tuokesalei Formation, Middle-Lower Devonian; 6, Altay Formation, Middle Devonian; 7, Lower Devonian; 8, Late Paleozoic monzonitic granite; 9, late Paleozoic plagioclase granite; 10, late Paleozoic tonalite; 11, late Paleozoic gabbro diorite; 12, faults; 13, anticline and syncline; 14, Ashele mining area; 15, geological boundary. The red arrows show affecting on Permian blocks by sinistral strike-slip.

ore deposit area suffered nearly E-W trending local compression, resulting in forming of a series of nearly N-S trending secondary folds in the volcanic rock basin. Those nearly N-S trending folds and fissures showed compression-shear features and had a certain sealed role, which induced the occurrence of the Ashele copper zinc massive sulfide deposit (Fig. 5).

The southwestern Tianshan is a world famous gold-mercury-antimony-rare metallogenic belt. In the eastern Uzbekistan, gold resources are extremely abundant. The super large Muruntau (64°32'E, 41°22'N) gold deposit possesses greatest reserves (Fig. 6, Mao et al., 2002a), with a total length of about 12 km mineralized belt. The deposit is located in the hinterland of the Dozier Kirkum desert in Uzbekistan, with an annual gold output of 21 tons (estimated production through other data may reach 80 tons), and a proved gold exploration reserves of about 5000 tons with an average grade of 2–11 g/t. Another 1830 tons of expectant resources may be found in the range of 1500 meters depth around the gold deposit (Mao et al., 2012b). The main fold in the Muruntau gold mining area (Fig. 6) is the Taskazgan anticline. Its axis strikes east-west, plunging eastward and with a dip angle of 15°–30°. The secondary fold, Muruntau anticline, formed at its southern wing. The strata exposed in the mining area range from Cambrian to Ordovician. The Besapen Formation is composed of metamorphic siltstone, sandstone and mudstone about 5 km thick. The lower layer of the mining area is carbonate-terrestrial-volcanic sedimentary rock series, and the upper part of that has a construction of terrestrial flysch.

Studies on isotope geochronology and paleontology show that the Besapen Formation is in fact a tectonically mixed rock series. The light colored rock veins are exposed on the edge of the mining area, two granodiorite stocks distributed in the southeast and in the central of the mining area, developed schistose flow cleavage zone, 10 km long and 1 km wide in the NW direction. Rocks crushed into breccia and mylonite. Some people called this belt “phyllitic myllonite” with strong silicification,

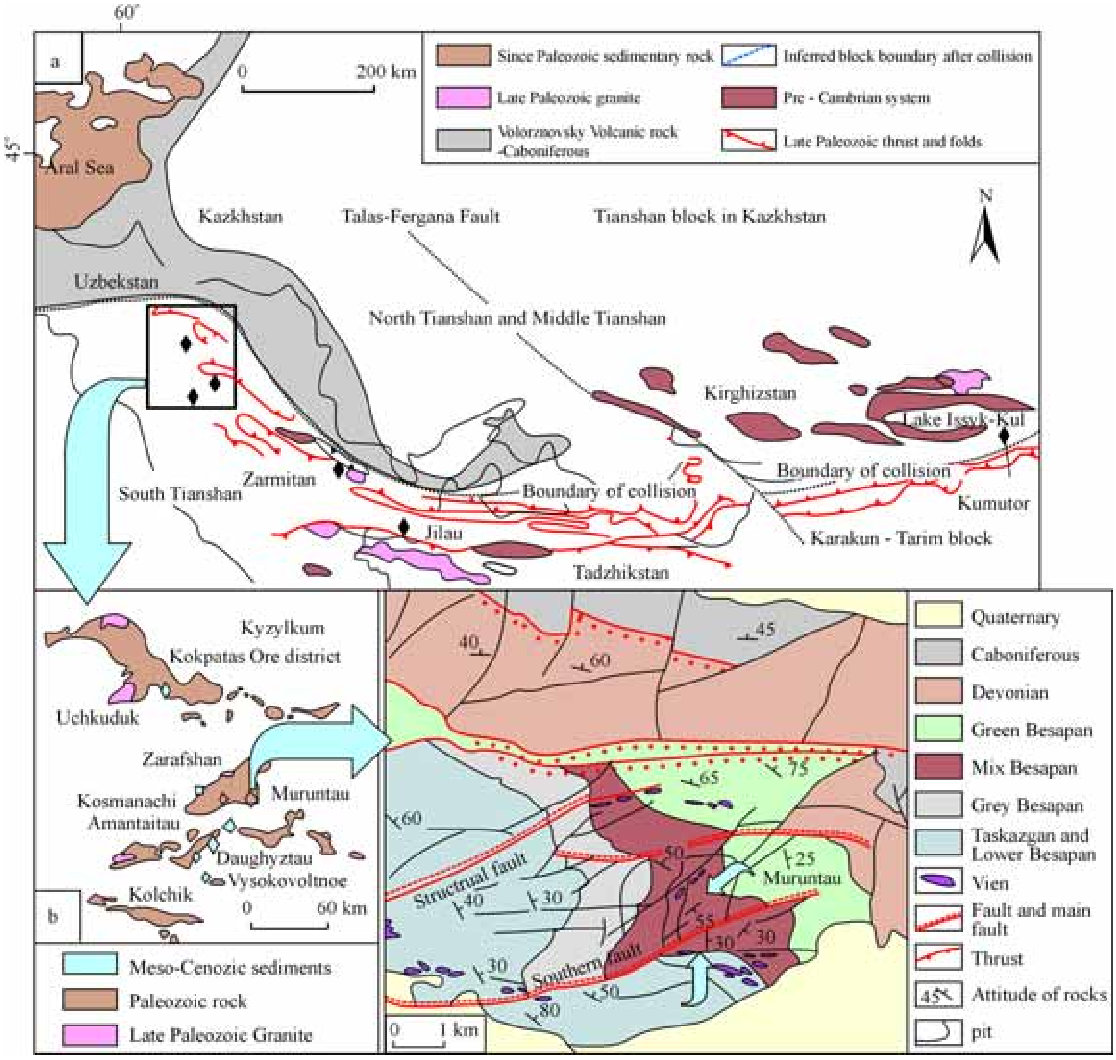

Fig. 6. Sketch geological maps of Muruntau gold deposit and mining area in the southwest Tianshan (according to Graupner et al., 2006; revised from Mao et al., 2012b).

biotitization and feldspathization. The gold deposit mainly occurred in a NW trending strong silicification zone. The attitudes of gold ore bodies are strictly controlled by a shear zone, i.e. ductile or ductile-brittle fracture system. The deposit is composed of a large number of net veins. Ore veins are usually 15–20 cm wide, containing pyrite with gold, arsenopyrite and quartz. The gold deposit as a whole is a large steep column body with complex structure and slightly dips to the east. The average content of sulfide in the veins is about 0.5%–1.5%, with the characteristics of multiple precipitation and re-distribution of gold element, and mixed with silver, copper, bismuth, lead, arsenic and iron. The average grade of silver is about 100–300 g/t. According to Rb-Sr, Sm-Nd and Re-Os isotopic ages acquired from minerals formed in the same period, the mineralization isotopic age of the Muruntau gold deposit is 270–290 Ma, namely in the Early Permian (Graupner et al., 2006). During this period, the E-W trending faults showed dextral strike-slip motions, and the mineralization may have occurred in the sinistral strike-slip fracture belt with NW trending. According to the study of Groves et al. (1998), the isotopic age of Muruntau tectono-magmatic activity of the Uzbekstan gold belt is 310 Ma, and the metallogenic age is 271–261 Ma. It is close to the research result conducted by Graupner et al. (2006). The compression and shear characteristics of ENE faults (bottom of Fig. 6) within the mining area are not conducive to the storage and enrichment of ore fluids.

Manifested by the data from two ultra-deep (more than 6000 meters) drilling wells in recent years, the source material of ore-forming in the Muruntau gold deposit is related to the granite from deep interior of the earth crust, rather than from the partly-coloured Besapen Formation or only associated with the syn-sedimentary process of the Early Paleozoic black rock series (Mao et al., 2002a). Affected by relatively eastward migration of the Baltic plate and Ural collision zone, NW and nearly E-W striking rock layers along foliation displayed moderately fracture with extension and shear, and formed high enrichment of useful deposit-forming elements in the vicinity of the faulting intersections, which constituted net-vein, overall steep and columnar ore bodies. Several years ago, some Chinese geologists used to be intent on search of the Muruntau type gold deposit only in black shale series in Xinjiang. It seems inappropriate now.

The E-W trending Tianshan collision zone was formed in the Late Devonian-Early Carboniferous period. However, during the Late Carboniferous-Early Permian period, nearly E-W trending faults underwent rather large-scale dextral strike-slip activities, which derived a series of ENE trending compressive-shear fissures, joints or small faults, and NW trending extensional-shear fractures or small faults. They usually develop excellent storage sites for metal hydrothermal deposits and bring a series of ore deposits in the famous Eastern Tianshan precious metal and polymetallic metallogenic belt (Fig. 7, Mao et al., 2002b). For example, the Xiangshan copper nickel deposit (No.16 in Fig. 7) and Huangshan East copper nickel deposits (No.18 in Fig. 7; Mao et al., 2003), as representatives, are all products of the Late Carboniferous-Early Permian mineralization.

The formation ages of some volcanic and magmatic type ore deposits (Tudun copper-nickel deposit, No.14 in Fig. 7; Erhongwa copper-nickel deposit, No.15 in Fig. 7; Xiangshan copper-nickel deposit, No.16 in Fig. 7; Huangshan copper-nickel deposit, No.17 in Fig. 7; Huangshan East copper-nickel deposit, No.18 in Fig. 7; Mao et al., 2003) , which are distributed along this zone, were mainly 300–282 Ma. The mafic-ultramafic rocks and copper deposits were mainly hosted in ENE trending secondary compressive-shearing brittle faults, which were derived from the main fault zones. The rich ore bodies mainly existed in local steep dipping and secondary tensile-shearing fracture zones.

The vast and major hydrothermal deposits (Nos. 1–13 and Nos. 19–21 in Fig. 7) were formed in a later period, mainly in the Late Permian (261–252 Ma; Mao et al., 2002a). It is inferred that the alteration and mineralization, closely related to magmatism, were mainly formed in the later period of the Late Paleozoic in this zone. It was formed in the period in which fault zones changed into dextral strike-slip faults rather than the product formed in the main collision period (385–323 Ma) in the Tianshan area. In short, these endogenetic metallic deposits formed in the Tianshan collision zone in the Permian came into being apparently after the breakout of collisions, namely the post collision period, during which regional faults in the interior of the plate adjusted to be a dextral strike slip fault.

The large-scale Tuwu porphyry copper deposit (No. 9 of Fig. 7; Mao et al., 2012a) was preserved in the nearly E-W trending Congultag subduction-collision zone, north to the main Tianshan collision zone with southward dipping faults plane of eastern Tianshan in the southernmost Junggar block. The ore-bearing rocks are mainly diorite porphyry and plagioclase granitic porphyry. The zircon U-Pb age of the ore-bearing intrusions (plagioclase granite porphyry) is about 356 Ma and the Rb-Sr isochronous age is about 369 Ma. They all intruded in the Late Devonian-Early Carboniferous period. The formation age of molybdenite is 322 Ma, that is to say, the metallogenic diagenesis occurred still in the early of the Late Carboniferous. Since the principal fault plane of the subduction zone was south dipping, the attitude of the Tuwu porphyry copper deposit is almost parallel to the main fault plane, also E-W trending with south dipping,

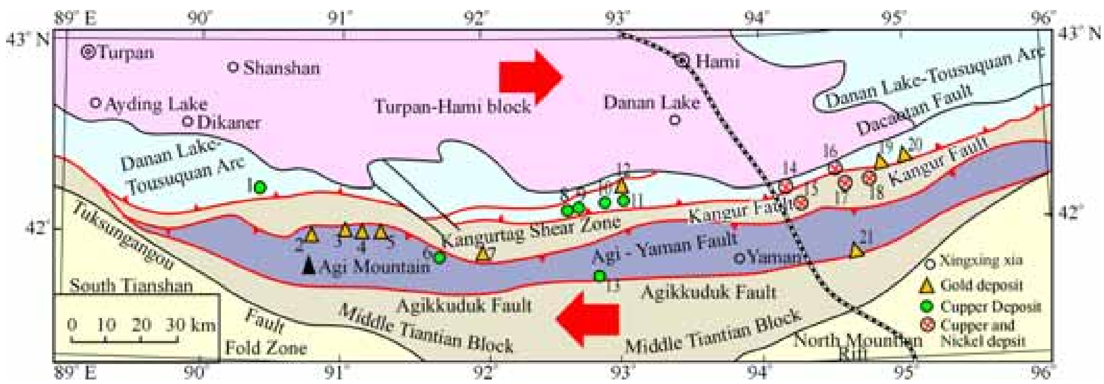

Fig. 7. Sketch geological map of precious metal and polymetallic metallogenic belt in eastern Tianshan (Turpan-southern Hami) (revised from Mao et al., 2002a).

Number and name of deposits: 1, Xiaorequanzi copper deposit; 2, Shiyingtan gold deposit; 3, Kangxi gold deposit; 4, Kangguer gold deposit; 5, Matoutan gold deposit; 6, Weiquan gold deposit; 7, Jiabaishan gold deposit; 8, Yandong gold deposit; 9, Tuwu copper deposit; 10, Linglong copper deposit; 11, Chihu copper deposit; 12, Xiaohongshan gold deposit; 13, Lubaishan copper deposit; 14, Tudun copper-nickel deposit; 15, Erhongwa copper-nickel deposit; 16, Xiangshan copper-nickel deposit; 17, Huangshan copper-nickel deposit; 18, Huangshan East copper-nickel deposit; 19, No.148 gold deposit; 20, Wutongwozi south gold deposit; 21, Baishigou gold deposit. The large red arrows show shear directions of the block during mineralization.

thus forming a large-scale ore body. The ore deposit is not hosted in the main fault plane, but in the secondary faults.

The famous super large Kumtor gold deposit and Pozzimuchuck skarn type copper gold deposit occurred in Kyrgyz in the western Tianshan Mountains. They were also formed in the Early Permian (^{40}Ar-^{39}Ar ages are between 288.4±0.6 Ma and 284.3±3 Ma) and mainly existed in the ENE trending dextral strike-slip fault zone and its secondary compression-shear fracture zones (Chen et al., 2010). Apparently it belongs to the mineralization in the intraplate deformation period after the collision.

In Oyu Tologoi, the south boundary area of Mongolia, there exists a super large porphyry copper gold deposit. This ore deposit is in the north of the central Balkhash-Tianshan-Hingganling Late Paleozoic (360–260 Ma) accretion collision zone. The Oyu Tologoi copper gold deposit occurred in the upper porphyry body of the Devonian. The surrounding rock is mainly acid to intermediate volcanic as well as volcanic-clastic rock and intruded by granitic rocks in the Early Carboniferous to the Early Permian period. According to the Re-Os dating of molybdenite, the formation age of the deposit is 373 – 370 Ma, namely it was formed in the Late Devonian (Nie et al., 2004, 2005; Zhang and Nie, 2010). It is an important example of mineralization during the main collision time of the Late Paleozoic. The deposit is obviously controlled by NNE-trending secondary tensile-shear faults, rather than being distributed along nearly E-W trending major regional faults in the collision zone.

To sum up, the period from Late Devonian to Early Carboniferous (385–323 Ma) is the main collision time of the Balkhash-Tianshan-Hingganling collision zone. The tectonic motion should be the most intense and the rocks were comparatively crushed. The ore-bearing fluid is very easy to migrate. The fractures could be easily penetrated to the surface, so it is prone to loss ore-bearing fluid. The ore bodies tended to accumulate and only occurred inside some smaller and secondary fractures, in the main collision period. Therefore, the mineralization rarely happened in the main collision period. However affected by weaker long-distance effect of Ural collision zone eastward migration in the Late Carboniferous-Early Permian period (323–260 Ma), the preexisting structural fissures in the Balkhash-Tianshan-Altay area moderately opened and many structural fissures did not penetrate to the surface, which made it very helpful to form deposits in this area and finally led to occurrence of a large number of super large endogenetic metallic deposits. It seems that the “orogenic metallogeny hypothesis” (Kerrich and Wyman., 1990; Barley and Groves, 1992; Groves et al., 1998; Goldfarb et al., 2001; Chen, 1996, 2000, 2006; Mao et al., 2012b) is not applicable to the Tianshan-Altay region in the central Asia continent. The “post orogenic period”, namely the intraplate deformation period after the collision, is the main period for forming many super large endogenetic metallic deposits.

4 Discussions and Suggestion

The Balkhash-Tianshan-Altay region lies within the Paleozoic collision zone and acts as the core of the Asian continental lithosphere, i.e. periphery accretion zone to the south of the Siberian plate. Originally composed of numerous small massifs in the southern hemisphere, they migrated with the Siberian plate to the middle-latitudes of the northern hemisphere and gained such tectonic framework fixed with the force of two collisions in the Early and Late Paleozoic (Wan, 2011), simultaneously forming some endogenous metal ore deposits in the moderate rupture section. During the late period of the Late Paleozoic (the Late Carboniferous and Permian), the region became a favorable position for the storage of endogenous metal ore deposits and numerous endogenous ore fields were formed, accordingly due to the influence of long distance effect induced from eastward migration of the Ural collision zone, a portion of fissures reopen moderately.

Abundant deposits were formed after the main collision period in the Balkhash-Tianshan-Altay region. As indicated in the statistics and research made by the authors, this is a rather common phenomenon in the Asian continent. The statistics on the relationships between the metallogenic epochs of 191 large and super-large endogenous ore deposits or ore fields in the Asian continent (Fig. 8) show that only 16 of those (8.4%) were formed in the pre-collision period; 36 (18.8%) coincided with the collision period (including the period of forming crystalline basement and the subduction-collision period);

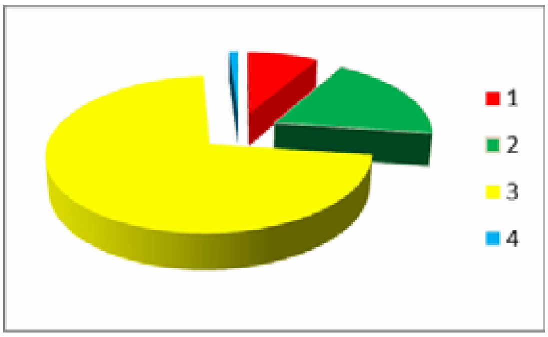

Fig. 8. The relationship among the period of endogenic metallogeny and collision, subduction or intraplate deformation.

1, Pre-collision period; 2, syn-collision or subduction period; 3, intraplate deformation period; 4, unknown.

137 (71.7%) were in the intraplate deformation period, or just located in the space of the collision zone, but actually formed after the collision period; only 2 have no definite relationship with the tectonics.

All these data indicate that large and super-large endogenous metal ore deposits in the Asian continent are prone to be formed during a moderate or less intensive tectonic period, i.e. during the period of intraplate deformation or post-collision. The ore deposits, formed in the syn-collision period, rarely occur in the main fracture plane, but in the secondary fracture belt close to the positions where tectonism is not so intensive.

Some Chinese scholars classified most endogenous ore deposits or fields as the "orogeny type" and proposed "the orogenic belt metallogeny hypothesis" (Cooke, et al., 2005; Chen, 1996, 2000, 2006; Mao et al., 2012a) or recognized that "orogenic belt is the best position to form endogenous ore deposits" and even maintained "more intense orogeny, more powerful metallogeny" (Qiu, 2002). The above recognition does not confirm the basic geological and tectonic facts in the Asian continent. The authors found and manifested that the giant endogenous ore deposits were mostly formed in the period of intraplate deformation or post collision. The above data in this paper exhibit that the endogenous ore deposits or fields are neither often formed in the strongest tectonic period nor in the violent tectonic position. Some endogenous metallogeny deposits can be formed in the secondary faults of the collision zone, however it is very difficult for those to occur in the main giant regional faults or thrusts. Some endogenous Metallogenesis deposits occurred and are located in the collision zone, but usually ore deposits are often formed in the post-collision period, which means that it is after the collision, the intra-plate deformation period. Metallogeny is very strong in the subduction zone between the conversion of oceanic and continental lithosphere (Groves, et al., 1998; Goldfarb, et al., 2001; Cooke, et al., 2005). However, the continent-continent collision is very different from the subduction. The orogenic belt metallogeny hypothesis may be explained well as that collisions in somewhere are relatively intensive and later under certain tectonism can easily form large ore deposits. Actually such mineralization has little to do with collision or so called "orogeny". This is quite different from the mechanism of the subduction zone mineralization and it could not be applied at random.

To sum up, the metallogeny research should be undertaken on the basis of making clear the constitution, genetic and industrial type of ore deposits. More efforts should be made on the research about metallogenic chronology, tectonic background and tectonic stress field in the process of ore formation, and then to make clear the reliable metallogenic prognosis.

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